A summary evaluation of SLR products of ILRS for IERS/ITRF

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During my CORE review panel presentation, I showed results from recent analyses of ILRS Normal Points to LAGEOS and LAGEOS 2 for site positioning and EOP time series. Since the ILRS Analysis Working Group is still in the process of formulating the "recipe" by which an official ILRS set of products will be generated, I had only access to a number of products submitted to the AWG during this planning stages, to make comparisons and draw conclusions from. Additionally, I used the independent evaluation of SLR solutions submitted to IERS/ITRF for the establishment of ITRF2000 by Zuheir Altamimi, to provide additional information on the quantity and quality of SLR solutions. While this summary is not a complete image of the presentation, (all of the viewgraphs will be deposited as PDF files for your reference), it is my intention to use the presentation material plus some additional that became available only in the recent days, to give you as complete a picture of what ILRS can deliver at present.

During the meeting I presented results from three "solutions":

- The ILRS ITRF2000 contributions (preliminary at the time, final now)
- Results from the last step of the ILRS Pilot Project solutions
- Preliminary results of a 1-year (1999) solution that included EOP rates

In this summary I have included Table 1 (a & b) which summarizes the preliminary and final Weighted RMS (WRMS) in position and velocity for all of the SLR solutions used in ITRF2000. From these tables we find that the consistency of the SLR solutions spans a wide range: 3-15 mm in position and 1-5 mm/y in velocity. It is obvious however that once the Pilot Project has "standardized" the processing of SLR data and the various ACs have benched-marked their s/w, ILRS will be capable of delivering products that are meeting the higher accuracy end of this range. This is simply a matter of time while some of the ACs are going through a learning curve.

Table 1a: *Before Editing (Original submission) statistics*

Solution	N	Pos. WRMS mm	Vel. WRMS mm/y	MSF
L AUS	54	10.70	4.10	.05641
L CGS	91	14.20	2.60	5.57565
L CRL	60	12.60	4.00	2.74816

L4 CSR	127	9.80	2.40	3.09817
L DEOS	90	11.80	4.60	7.02571
L DGFI	43	13.20	2.90	15.39293
L JCET	**50**	**5.20**	**1.30**	**8.10320**

Table 1b: *After Editing (Final selection) statistics*

Solution	N	Pos. WRMS mm	Vel. WRMS mm/y	MSF
L AUS	52	9.40	4.00	.05641
L CGS	91	13.60	2.50	5.57565
L CRL	60	10.00	3.90	2.74816
L4 CSR	127	9.40	2.40	3.09817
L DEOS	87	10.90	4.60	7.02571
L DGFI	38	8.50	2.70	15.39293
L JCET	**40**	**2.40**	**1.20**	**8.10320**

The diversity of the ITRF2000 contributions' quality was also reflected in the results that were submitted to the ILRS Pilot Project. In summary here we find that monthly solutions for mean positions can vary up to ~5 cm in RMS, and the scale differences are at the 1-2 ppb level. Again, these are the result of inconsistent modeling, application of constraints, etc. and we are confident that they can be corrected in the next step of the Pilot Project, if not already.

The final item on the above list addressed solely the EOP series issues. Specifically, what we hope to start delivering routinely to IERS "very soon". They were based on a preliminary solution for the year 1999, and it will be submitted to the Pilot Project for review. In this solution we were forced to follow certain rules that apply to the ILRS Pilot

Project, so the data processing is not exactly optimal (as it is the case in our IERS/ITRF submissions). This fact, in addition to the fact that this is the first attempt to estimate EOP rates, are enough reasons to view these results as preliminary in what SLR can truly offer in EOP rates. The RMS daily differences with respect to IERS C04 (**raw differences**, see discussion following this), are:

- **X-dot pole** **734 µas/d**
- **Y-dot pole** **1124 µas/d**

An item that was discussed at the meeting with regards to the SLR EOP series quality in general, was the comparison of the series that we submitted to IERS in 2000, versus the combination series IERS C04. I pointed out that due to an oversight in the treatment of the series, (IERS did not account for the fact that we reported the data at 12 hrs UTC instead of 0 hrs UTC), our comparison to IERS C04 gave a very distorted picture of SLR EOP quality. Further to that, I raised the issue that all of my comparisons were done without any smoothing of the SLR series, while IERS C04 is slightly smoothed. While this was refuted by Daniel Gambis and Tom Herring during the meeting, I went back to the recently published 1999 IERS Annual Report (pages 38-39) as well as the on-line (web) Guide to IERS C04 and recovered the details about its formation as they are officially published by IERS. These confirm my statement about smoothing of C04. I reproduce below the tables that show the level of smoothing applied to these series:

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EOP(IERS) C04 was computed over six successive intervals, 1962-1967,
 1968-1971, 1972-1979, 1980-1982, 1983-1987 and 1988-present. After being
 homogeneized and merged, the contributing series of each of the EOP are
 slightly smoothed by Vondrak algorithm in order to remove the high-frequency
 noise.

   The two tables below give :
      1 - The caracteristics of the smoothing adopted for each period (the
          variations with periods shorter than the value in the table are
          smoothed out, except the short term variations in UT1 due to zonal
          tides and the 14d terms in celestial pole offsets, see above)
      2 - The uncertainty of one daily value of EOP for each period .
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Table 1a. Frequency filtering characteristic of smoothing for EOP(IERS) C 04 Pole Components.

Epsilon	PERIOD FOR REMAINING AMPLITUDE 5%	50%	95%	Year
1E -0.6	3.2d	10.0d	17.0d	1983-1985
1E +0.6	2.0d	6.3d	10.7d	1986-1989
1E +1.0	1.7d	5.4d	9.2d	1990-1991
1E +1.4	1.5d	4.5d	7.9d	1992
1E +1.6	1.4d	4.2d	7.3d	1993
1E +2.0	**1.2d**	**3.7d**	**6.3d**	**1994-1999**

Table 1b. Frequency filtering characteristic of smoothing for EOP(IERS) C 04 Universal Time.

Epsilon	PERIOD FOR REMAINING AMPLITUDE 5%	50%	95%	Year
1E -0.5	3.0d	9.6d	16.3d	1983-1987
1E +0.2	2.3d	7.4d	12.5d	1988-1989
1E +1.0	1.7d	5.4d	9.2d	1990-1991
1E +1.5	1.5d	4.5d	7.6d	1992-1993
1E +2.0	**1.2d**	**3.7d**	**6.3d**	**1994-1999**

Table 2 - Uncertainty of one daily value for the EOP(IERS) C 04

Period		1962-1967	1968-1971	1972-1979	1980-1983	1984-1995	1996-1999
X	**(mas)**	**30**	**20**	**15**	**2**	**0.7**	**0.2**
Y	**(mas)**	**30**	**20**	**15**	**2**	**0.7**	**0.2**
UT	**(0.1ms)**	**20**	**15**	**10**	**4**	**0.4**	**0.2**
LOD	(0.1ms)	14	10	7	1.5	0.3	0.2
dPsi*sin(eps)	(mas)	12	9	5	3	0.6	0.3
dEpsi	(mas)	2	2	2	2	0.6	0.3

From these tables we reach two conclusions: (a) the series **IS** smoothed down to ~6.3 days, and (b) the quoted accuracy for the period 1996-present is 0.2 mas for x and y of

Daily EOP Comparison: (JCET) L12p 2001 wrt (IERS) C04

Period covered: 1993/01/03 - 2000/12/31 (2921 days)

JCET-IERS C04	ΔX [mas]	ΔY [mas]	ΔLOD [μs]
Minimum	-1.8	-1.9	-420.56
Maximum	1.6	1.6	407.43
Points	2911	2902	2912
Mean	0.0	0.0	0.1
RMS	0.29	0.27	47.92
Std Deviation	0.29	0.27	47.93

NOTE: Δx, Δy edited to within ±2 mas and ΔLOD to within ±500 μs

the pole, and 20 μs for LOD. Based on these facts, I have applied the exact same Vondrak smoothing to the new (2001 submission) of the JCET daily EOP series and I have created similar plots and statistics like those that were presented at the meeting for last year's (NOT smoothed) submission. The RMS differences, after taking out a linear trend in the pole coordinates due to the difference in Reference Frames, is shown in the above table.

Although IERS C04 does contain to some extent information from SLR series, we can use the assumption of orthogonal errors between IERS C04 and the particular solution which is certainly not used in the combination yet. Doing so through a multiplication of the standard deviations with $\sqrt{2}/2$, results in the following rough estimate of the calibrated accuracy of the SLR series:

- **X Pole** **205 μas**
- **Y Pole** **191 μas**
- **LOD** **34 μs**

These are the estimates from an **eight-year** solution for **daily values**, where as one can verify from the above table, only in twenty days or less, SLR reported highly erroneous values due to either lack of data, poor geometry, or other reasons. I would submit that these numbers are very representative of current SLR capabilities for EOP daily products, and they can be further improved if a few additional select targets are used in the data reduction process (e.g. the ETALONs, Ajisai, Starlette, Stella, and perhaps WESTPAC).

In summary (revised from actual presentation on the basis of recent results):

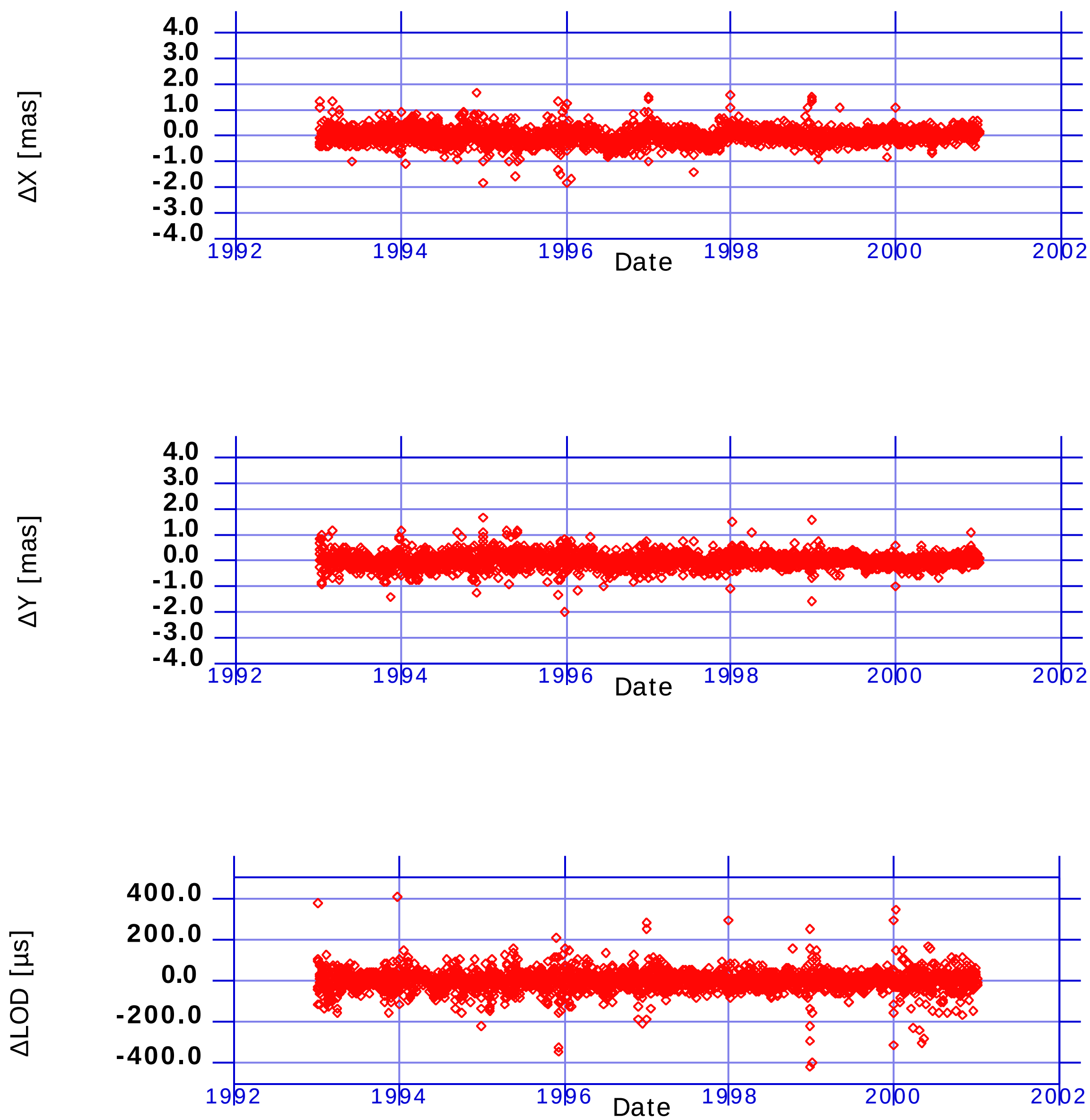
The combined analysis of **SLR** data from **LAGEOS 1 & 2** produces accurate, high resolution determination of Earth kinematics (**EOP**) with **daily resolution**, and provides an independent source of EOP information (**x, y, LOD, xdot, ydot**) to IERS.

Comparisons to other **SLR** solutions and independent techniques indicate that the **scale** uncertainty is at **< 1 ppb** and the weighted RMS difference in **position** and **velocity** at **2.4 mm** and **1.2 mm/y** respectively.

EOP series of daily averages have internal precision of **~160 μas** in Pole **x** and **y**, and the newly derived products of **x and y rates**, indicate internal precision of **~250 μas/d**. The **LOD** corresponding number is **300 μs**.

External comparisons to **IERS C 04** and **IGS** series, indicate that the accuracy of these estimates is ~**250 μas** for **x** and **y**, ~**40 μs** for **LOD**, and ~**900 μas/d** for **xdot** and **ydot**.

Vondrak Smoothed EOP (JCET) 01 L12p Differences from EOP (IERS) C04



Raw EOP rates from a preliminary annual solution for 1999